A Novel Level-of-Detail Technique for Virtual City Environments

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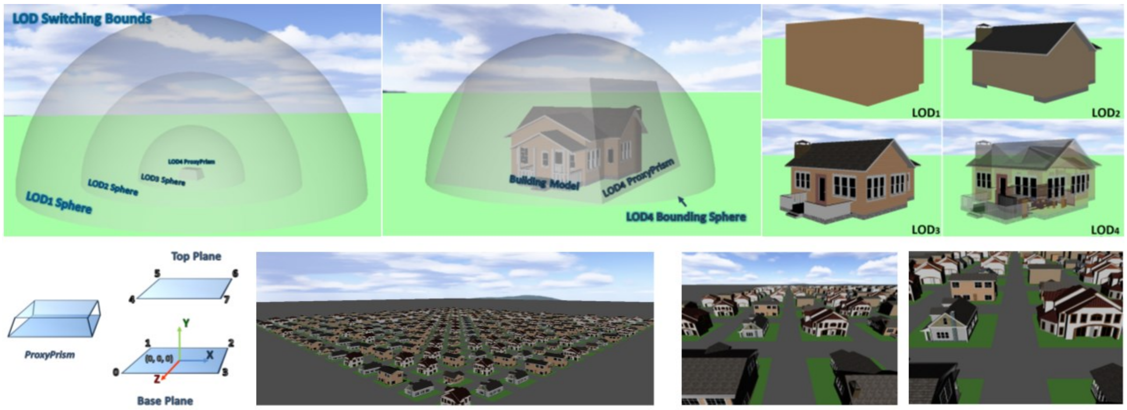

Figure 1: *ProxyPrism LOD Technique and Evaluation; bottom right: different sFOVs from the same world position*

Abstract

Virtual City Environments (VCEs) and Mirror Worlds can be a useful resource for communities such as the local government, researchers and the general public to collaborate on tasks like town planning, threat assessment, commerce and research. In this work, we focus on runtime data structures and performance for Level-of-Detail (LOD) management to deliver real-time portrayal. We implement and evaluate a novel X3D-based Level-of-Detail technique called ProxyPrismLOD, which leverages the CityGML standard of a 4-step LOD hierarchy to optimally encapsulate irregularly and asymmetrically shaped building models. First, we ran a user study to understand the visual dynamics of range-based LOD switching and derived a scaling factor of 3. Second, we ran a series of simulations to study the performance benefits of ProxyPrismLOD technique over the basic range-based LOD. We observed performance benefits up to 7.46% in terms of overall Frames-per-Seconds (FPS) on the models we tested.

Keywords: Level-Of-Detail, Extensible 3D (X3D)

Concepts: • **Human-Centered computing ~ Interactive Paradigms;** *Virtual Reality;*

1 Background

There have been many different approaches to managing Level-of-Detail (LOD) in computer graphics applications [Luebke at al., 2002]. We propose a novel LOD technique for Virtual City Environments (VCEs), which is designed and implemented in X3D [Brutzman & Daly 2009, Web3D] and optimized specifically for VCEs to provide faster and more specific LOD management by incorporating the semantic definitions and structure of 3D buildings in the LOD technique. We have used the CityGML standard [Kolbe, 2009] as the basis for describing 3D building models and demonstrate a switching technique specifically tailored for VCEs. We call our technique the 'ProxyPrismLOD' technique (Figure 1).

There are many LOD techniques in use by different applications and standards to improve runtime performance. In this work, we develop and evaluate a novel LOD technique which is designed specifically for delivering VCEs through a Web3D Service [Schilling et al., 2009] where buildings and city blocks are not symmetric in 2 or 3 dimensions. The main contributions of this work are listed below:

- Implement and evaluate a novel LOD technique, that uses simple and easy-to-use definitions to manage highly-detailed 3D data such as building interiors.
- Devise a discrete switching function for implementing range-based switching across LOD models. This function takes into account the size of the building model and the size of the geographical coverage.
- Evaluate the effect of Software Field-of-View (sFOV) on the switching function and empirically evaluate performance in terms of subjective metrics ("visual continuity" and "distraction" levels) and rendering performance (FPS).

2 Switching Ranges & User Experience

From the lowest level of detail (LOD1) to the highest (LOD4), model properties (such as vertices, shapes and texture) grow in size and complexity at an exponential rate. Based on this observation, we describe a cutoff function for range-based LOD switching:

$$Y = \alpha \,.\, \beta \,.\, \gamma^{x}$$

Where:

α = longest diagonal of building
β = scaling factor
γ = plot radius
$\{ \forall x \in \Re: 0 \leq x \leq 1 \}$

As the switching distances or the LOD cutoffs are scaled with β, we observed that the rendering is the smoothest for $\beta = 1$ and most discontinuous for $\beta = 4$ for both sFOV conditions. Therefore, from the standpoint of the performance, a β with the smallest value is preferable. However from the standpoint of the distraction from LOD switching, a higher β is preferable.

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Our first experimental evaluation of our LOD technique was intended to understand the visual impact of our LOD switching parameter 'scaling factor' for different fields of view. A wider field of view for the virtual camera means that more of the scene is visible at once and thus there is a greater chance to see models popping in and out. Software Field of View (sFOV) was compared between two levels **(**LOW = 45 degrees vertical**,** HIGH = 75 degrees vertical**)**. To determine the cutoff values for our experiment (Y), we used values of $x = 0.33$; $x = 0.66$; $x = 1.0$ and varied the scaling factor β as a within-subjects independent variable.

We ran a human-subjects study and measured the subjective ratings of each user's perceived smoothness, visual granularity and distraction levels for each scaling factor and sFOV. Stimuli for each condition (2 x 4 = 8) was prepared by generating a city grid of 20 x 20 square plots with an equal number of each building type, randomly located (see Figure 1, bottom). For each world, an animated camera path was generated with an equal number of waypoints through the city 50 meters above street level. Participants observed and rated every animated path on a 65 inch HDTV with a physical FOV of 45 degrees.

The study was conducted for 12 participants in the age group 19-43, of which 10 were graduate students. In their preference of sFOV, 66% preferred using high sFOV because of the greater viewing angle. We performed one-way ANOVA analysis on the data collected for questions 2 and 3 with both sFOV conditions. We observed significant difference overall with $p < 0.0001$. In order to determine significant differences between all pairs, we performed Means Comparisons using Tukey-Kramer HSD. The results (Tables 1 and 2) show that there was no significant difference between $\beta = 3$ and $\beta = 4$ runs in terms of distraction levels. These results suggest that a $\beta = 3$ will be most optimal in terms of both visual smoothness and distraction levels.

3 Runtime Performance

This was a 2 x 2 design where we compared our ProxyPrismLOD implementation with our range-based implementation under two different Software Field of Views (sFOV). Again, we compared two levels**:** LOW = 45 degrees vertical and HIGH = 75 degrees vertical. We generated 10 different city models of size 20 x 20, again using an equal number of the 4 different building models space on a uniform square grid. We perform this experiment on a set of 10 animated paths in the VE. Each path was tested over the four conditions (High vs. Low sFOV and ProxyPrismLOD vs. Range-BasedLOD) with the same animated path and the same VCE. Since the animated path is randomly generated, the total distance covered during an animation varies across the 10 runs. In order for valid comparison, the camera speed is kept to a constant 20 meters/second. The browser collects approximately 30 samples/ second and an average path lasts around 70 seconds; this yielded approximately 2100 samples for every run.

We aggregated the samples according to the two independent variables: LOD technique and sFOV (see Tables 2 and 3). Therefore we have 20 observations in each group. When subjected to T-Tests, there are significant differences in both LOD techniques and sFOV groups. A significant difference between HIGH and LOW sFOV confirms our intuition that wider sFOV incurs a higher rendering load ($p < 0.0001$). Also, a significant difference between ProxyPrismLOD and range-based LOD demonstrates that our technique significantly outperforms the range-based LOD technique ($p < 0.0001$). We calculated the performance improvements in each simulation across all conditions. The percentage benefit is calculated using the formula:

$$\textbf{\% benefit} = \frac{FPS_{PP} \ \text{x} \ FPD_{DB}}{FPS_{DB}} \text{ x } 100$$

Where:
FPS_{DB} = Average FPS for Range-Based LOD Technique;
FPS_{PP} = Average FPS for ProxyPrismLOD Technique;

TABLE I. *FPS ANALYSIS OF OUR LOD TECHNIQUES*

	Proxy Prism		**Range-based**	
	Low sFOV	***High sFOV***	***Low sFOV***	***High sFOV***
Average	31.921	30.171	31.199	29.029
St DEV	0.525	0.686	0.873	0.701

TABLE II. *PERFORMANCE BENEFITS USING PROXYPRISMLOD*

	Proxy Prism		**Range-based**	
	Average	***Maximum***	***Minimum***	***Std. Dev***
Low sFOV	2.36 %	7.38 %	0.01%	2.36 %
High sFOV	3.96 %	7.46 %	0.42 %	2.56 %

3 Conclusions

The first experiment was in the form of user study to evaluate an optimal scaling factor for an LOD cutoff function that is based on the building size and plot size. After analyzing the results, we concluded that $\beta = 3$ is the most optimal scaling factor in terms of smooth model switching and lower distraction levels. The second experiment measured the FPS performance benefits of using our ProxyPrismLOD. We showed that our ProxyPrismLOD technique can outperform range-based technique by greater than 7%.

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